Motion Navigation using Non-Linear Gradient Fields

Emre Kopanoglu[1], Gigi Galiana[1], and Robert Todd Constable[1]
[1]*Diagnostic Radiology, Yale University, New Haven, Connecticut, United States*

Target Audience: Researchers with an interest in motion tracking or nonlinear gradient fields.

Purpose: Nonlinear gradient fields (NLGFs) vary along at least two directions. Thus, a simple trapezoidal waveform using NLGFs encodes data along at least two dimensions. Supported with a receive-array RF coil, such an acquisition may be used to form low-resolution 2D/3D images for motion navigation. In this study, we demonstrate this approach using a Z2-harmonic ($z^2 - x^2/2 - y^2/2$) and an 8-channel head coil.

Methods: Simulations were performed using Matlab (Mathworks Inc., Natick, MA, USA) with a spatial resolution of 256^2 and an FOV of $(20\ cm)^2$. The duration of the motion encoding gradient was 2.56 ms, its amplitude 4 mT/m^2 and the number of navigator samples 128. Samples were acquired during ramp-up and ramp-down, with the flat-top of the trapezoidal waveform being 1.36 ms. In the simulations, the experimentally obtained sensitivity maps of an 8-channel receiver coil (Figure 1) were used [1]. The proposed imaging sequence, used NLGF and a representative voxel distribution are illustrated in Figure 1. The spatial encoding functions generated by the gradient fields were averaged on a 16×16 higher resolution grid (sufficient at the field strength used) to incorporate intra-voxel dephasing.

Motion was assumed to be sinusoidal with some randomness imposed (Figure 2) for simplicity. Each TR ($TR\#i$) was simulated as follows: the target image was translated / rotated; image data were acquired using the coil sensitivities and the Fourier Transform after which the corresponding line in the k-space was selected and stored (ACQ^i_{im}); navigator data were acquired using the spatial-encoding function generated by the NLGF and the coil sensitivities (ACQ^i_{mot}). 2D Motion navigator images were reconstructed using Kaczmarz algorithm with 15 iterations and $\lambda = 0.25$. The first navigator image was set as reference. All succeeding images were translated and rotated in a predefined range of values, and their complex inner product with the reference image was calculated. The translation & rotation values that yielded the magnitude-wise maximum inner-product were stored ($\Delta^i_x, \Delta^i_y, \Delta^i_\phi$). Object images were reconstructed by taking the inverse Fourier Transform of the stored k-space line (ACQ^i_{im}), and translating/rotating the resulting spatial pattern by ($\Delta^i_x, \Delta^i_y, \Delta^i_\phi$) before adding it to the reconstructed image.

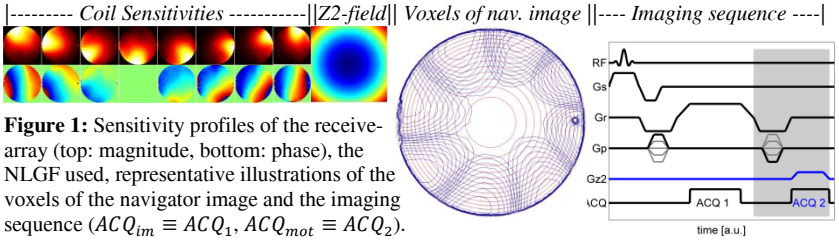

Figure 1: Sensitivity profiles of the receive-array (top: magnitude, bottom: phase), the NLGF used, representative illustrations of the voxels of the navigator image and the imaging sequence ($ACQ_{im} \equiv ACQ_1$, $ACQ_{mot} \equiv ACQ_2$).

Because a nonlinear field and multiple receive coils were used, reconstructed images had noticeable central-brightening. This central brightening does not inhibit motion tracking but dampens the estimated values in a linear fashion. Hence, the motion pattern is well-recovered but scaled. To correct this, the estimated motion is scaled in a range of values, images were reconstructed for each scaling and the sharpest image was selected using the gradient of the image along both transverse dimensions as a measure of sharpness. We would like to stress here that, the images given in Figure 2 are generated by a fully-automated algorithm that includes all the steps, and has neither any user-input nor any knowledge on the shape of the motion or the target image.

Results: Figure 2 shows the estimated motion, and the motion-corrected images for translational motion along x and y, and rotation around z axes in axial images. Average estimation error is below 0.17 mm (0.22 pixels) for translational and 0.4 degrees for rotational motion.

Discussion: For this proof-of-concept study, the motion navigator waveform was not time-optimized and relatively low gradient amplitude and sampling rate were used. By adjusting the NLGF amplitude such that field strength and field rate-of-change are same inside the FOV as those of the linear gradient fields typically available clinically (40 mT/m, 140 T/m/sec), and using the maximum available sampling rate, the duration of the navigator can be reduced to approximately 250 μs. If the navigator is placed before the data acquisition, then multiple echo sequences are possible, with only a 500μs increase in echo-time including rewinding. If used after data acquisition, the method requires rewinding the phase and readout gradient moments.

In its current state, the proposed method can track in-slice translational and rotational rigid body motion. However, because data-acquisition with the NLGF represents a projection imaging sequence, the center of k-space is acquired in each TR. Hence, the presence of through-plane motion can be estimated similar to PROPELLER [2]. Furthermore, because the field varies in all three dimensions, it may track and correct through-plane motion and rotation around x and y axes in slab-imaging cases, using an RF coil-array with separate elements along z.

Fourier Shift Theorem based methods assume that the object and the coil sensitivities do not change due to motion, which necessitates that the coils move with the object[3]. The proposed method does not have this requirement; to demonstrate this, the method was demonstrated for a case with stationary coils.

One of the advantages of this approach is that it can be seamlessly integrated with the accelerated-acquisition method O-Space imaging [4] with the pre-phasing waveform before readout.

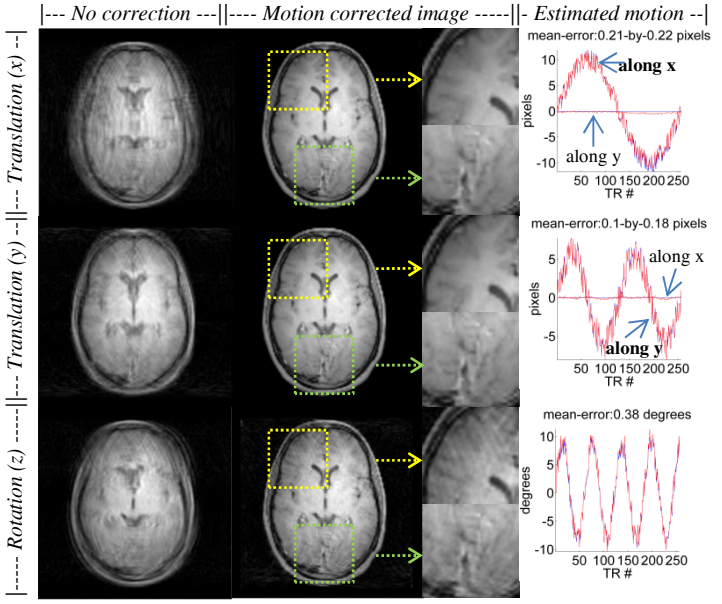

Figure 2: The proposed method is demonstrated on in-slice translational and rotational motion. **Middle column:** Parts of the corrected images are magnified to demonstrate correction performance with more clarity. **Right:** Estimated (red) and actual (blue) motion patterns are given on the right.

Conclusion: In this study, a novel motion navigation method that uses RF receiver arrays and nonlinear gradient fields is proposed. As demonstrated, the method can track rigid in-slice translational and rotational motion with sub-pixel precision, whereas tracking of through-plane motion is currently under investigation.

Acknowledgments: NIH R01-EB016978 & R01-EB012289. **References:** 1. Walsh DO *et al.* MRM 2000;43(5):682-690. 2. Pipe JG. MRM 1999;42(5):963-969. 3. Bookwalter CA *et al.* IEEE MI 2010;29(2):339-349. 4. Stockmann JP *et al.* MRM 2010;64(2):447-456.